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FILTER PAPER STUDIES II

EFFECT OF REPLACING ESPARTO WITH WOOD PULP FIBER

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NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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NRL REPORT NO. C-3225

FILTER PAPER STUDIES II
EFFECT OF REPLACING ESPARTO WITH WOOD PULP FIBER

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East Walpole, Massachusetts

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Problem No. 32C04-05 January 22, 1948

NAVAL RESEARCH LABORATORY
CAPTAIN H. A. SCHADE, USN, DIRECTOR
WASHINGTON, D.C.

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PREFACE

This Naval Research Laboratory Report consists of two Research and Development reports written by the Hollingsworth and Vose Company, East Walpole, Massachusetts, on Navy Contract No. N6-ORI-209. These reports are identified as follows:

> Research and Mill Trial on the Development of a Domestic Substitute for Esparto Fiber in the Navy Type H-60 Filter Paper, First Quarter of Contract No. N6ORI-209, referred to as the N-3 Trial.
>
> Research and Mill Trial on the Development of a Domestic Substitute for Esparto Fiber in the Navy Type H-60 Filter Paper, Second Quarter of Contract No. N6ORI-209, referred to as the N-4 Trial.

This report concludes the work on the first half of contract N6-ORI-209. Filter paper studies are being continued by the Hollingsworth and Vose Company and additional reports will be published when received.

CONTENTS

ABSTRACT

This is an interim report describing in detail two mill runs and the associated laboratory work on the effects of replacing esparto with wood-pulp fiber in the Navy H-60 filter paper. It is shown that an extremely good paper can be manufactured using causticized wood-pulp in place of esparto fiber. However, the paper "relaxes" considerably after manufacture to give a product similar in performance to the H-60 paper. It is shown that the "flexing" effect can be eliminated partially by spray treatment of the wet paper with wetting agents with considerable loss in paper strength. The relaxation, flexing, and "break" effects all require further study.

RESEARCH AND MILL TRIAL ON THE DEVELOPMENT OF A DOMESTIC SUBSTITUTE FOR ESPARTO FIBER IN THE NAVY TYPE H-60 FILTER PAPER (N-3 TRIAL)

INTRODUCTION

This report covers the work done for the first quarter of contract No. N60RI-209. A statement of the general objectives together with an outline of the previous work done is contained in NRL Report C-3172*.

The mill trial reported here is designated as the N-3 trial, H & V Lot No. 9798, dated December 16, 1946.

On the basis of laboratory handsheet data, it was decided to work with a furnish which contained no esparto or yucca fibers. Whereas yucca was demonstrated to be a satisfactory substitute for esparto in the Navy type H-60 filter paper, no commercial facilities are or hand for harvesting yucca, and it was thought desirable to extend this study to include fibers which are more generally available in this country.

LABORATORY WORK

Considerable exploratory work was done on a number of wood-pulp fibers. The one which showed the greatest promise for this application was a causticized kraft treated in accordance with the Krafelt Patent. †

The outstanding feature of this fiber is its freeness to the passage of air when felted into a sheet of paper. It is perhaps best characterized by the heterogeneous length and the curly nature of the fibers.

In accordance with our present theory on the homogeneous distribution of asbestos fibers in filter paper, other fibers were selected which would give to some extent a stepwise graduation of fiber size from the largest down to the smallest. In this case, the largest fibers are the rope fibers which seem to be required to impart strength to the sheet. The smallest fibers are the asbestos fibers. Of those fibers tried, various combinations of the following appeared to give the best asbestos distribution: 1) rope fibers (sisal) 2) causticized kraft 3) cotton flock 4) rayon flock (1.5 denier) 5) asbestos.

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* Knudson, H. W., "Filter Paper Studies I. Effect of Replacing Esparto with Yucca Fiber," NRL Report C-3172, September 1947 (Confidential)

† McCormick and Schwartz, U. S. Patent No. 1,857,100, May 3, 1932

Although more laboratory work is required for choice and proportions of these fibers, the following furnish gave good laboratory results:

10% Rope
40% Causticized kraft
25% Cotton flock
10% Viscose rayon flock (1.5denier)
15% Blue bolivian asbestos

Table I gives typical performance data on handsheets made from the above stock prepared in a laboratory beater.

TABLE I

Performance Data of Handsheets

Sample	DOP Penetration (%)	Resistance (mm H_2O)	Efficiency (%)	Flexed DOP Penetration (%)	Flexed Resistance (mm H_2O)	Flexed Efficiency (%)
1	.070	132	2.37	.055	127	2.56
2	.090	125	2.44	.062	113	2.84
3	.070	131	2.40	.052	118	2.78
4	.078	130	2.39	.052	118	2.78
5	.082	130	2.37	.062	117	2.74
6	.070	132	2.39	.045	114	2.94
7	.082	128	2.41	.055	114	2.86

The above samples undoubtedly show the best performance of any non-esparto paper on record at this company. The effect of flexing is recorded in the last three columns. There is not yet a clear explanation of the flexing effect, but it is thought to be due to superficial hydration of some of the fibers which causes them to be weakly cemented together. Flexing the paper may break the bond between the fibers and thus allow more fiber surface to be exposed by allowing each fiber to act independently.

In an effort to minimize the effect of any hydration, it was thought that the addition of a surface-active agent might be helpful.

The samples in Table II were spray-treated with a typical wetting agent, e.g., Nacconol NR before drying. Otherwise the samples may be considered to be just the same as those in Table I.

TABLE II

Performance Data of Handsheets Treated with a Wetting Agent

Sample	DOP Penetration (%)	Resistance (mm H_2O)	Efficiency (%)	Flexed DOP Penetration (%)	Flexed Resistance (mm H_2O)	Flexed Efficiency (%)
1	.072	113	2.78	.082	106	2.91
2	.056	118	2.76	.058	110	2.94
3	.040	126	2.69	.042	118	2.86
4	.035	123	2.80	.045	113	2.96
5	.095	113	2.68	.080	109	2.84

These data show a marked improvement over the data in Table I, but the last three columns show that not all of the flexing effect has been eliminated. Further, these data show that the spray-treated samples have lower penetration and resistance readings than the untreated samples. It should be pointed out that the treated samples were very soft and quite weak in strength.

Table III shows the rate of "break" with exposure to DOP smoke on a spray-treated laboratory handsheet.

TABLE III

Effect of DOP Exposure on Performance
for Spray-Treated Laboratory Handsheet

Time of Exposure (Min.)	DOP Penetration (%)	Resistance (mm H_2O)
0	.044	121
1	.045	121
2	.044	122
3	.045	123
4	.045	123
5	.044	124
8	.046	124
10	.048	124
15	.050	125
20	.054	126
25	.056	126
30	.060	127
35	.062	128
40	.064	129

This rate of "break" is unusually slow. Allowance should be made for variation in smoke concentration, fatigue of photocell, and change in "owl" reading. Although efforts were made to hold these readings constant, some variation could occur in the time elapsed during the test. However, by comparison with other papers tested under similar conditions, this sample showed excellent resistance to "break". On the basis of these tests, it was decided that at least a portion of the production run should be spray-treated.

It has become standard practice to test for pin holes in this grade of paper or for poor distribution of asbestos by measuring the smoke penetration at various flow rates through the sample. Table IV gives these data on a typical laboratory handsheet treated with the spray.

The flow was continuous with the rate being first decreased and then increased. This sample shows a normal decrease in penetration with flow and it may be assumed that there were no pin holes and that the distribution of asbestos was good.

THE MILL RUN

Preparation of Stock for Mill Trial

The preparation of the causticized kraft was carried out according to a standard practice followed at this mill. Laps of kraft pulp were loaded into a rotary boiler and

TABLE IV

Performance vs Flow Rate
for Spray-Treated Handsheet

Sample Flow Rate (l/m)	DOP Penetration (%)	Resistance (mm H_2O)
85	.046	120
64	.044	90
42½	.035	60
21	.018	30
42½	.032	60
64	.038	90
85	.042	120

treated at room temperature with a 17½° Be' solution (approximately 12 2/3%) sodium hydroxide. The ratio of stock to solution was 1:5. The boiler was rotated with no addition of heat for 4 to 5 hours after which the stock was dumped and allowed to drain. This stock was then furnished to a beater and washed one hour with warm water and from 1 to 2 hours additional with cold water to remove the caustic. The causticized kraft is then ready for use.

Manufacturing Data for N-3 Trial

Each of two beaters was furnished with the following:

240 lb	Causticized kraft	- 40%
150 lb	Cotton flock	- 25%
60 lb	Viscose rayon flock	- 10%
60 lb	Rope fibers (prepared)	- 10%
90 lb	Blue Bolivian asbestos	- 15%
600 lb		100%

The asbestos was furnished to the beater first and given a hard beat for about 15 minutes. At the end of this time the asbestos was well defibered.

The beater roll was then raised and the stock circulated in the beater while the remainder of the furnish was added. The causticized kraft was added first followed by the rope, cotton flock, and rayon flock in that order. No further beating was done, but the stock was allowed to circulate for at least 20 minutes to insure thorough mixing of all the fibers. At the end of this time the stock was dropped to a chest from which it was pumped to a Fourdrinier machine for felting into paper. No additional asbestos was added from the auxiliary asbestos feed line.

No difficulty was experienced in handling this paper over the machine. In general, the formation and appearance were good.

Performance of the Paper

Averages of physical tests on this untreated paper are recorded below. It should be pointed out that in the range of these tests, the tear and tensile measurements are not

considered too accurate. However, this paper handled much the same as H-60 paper and it is believed that there would be no difficulty in fabrication of the filter in the Navy canister.

TABLE V

Physical Tests of N-3 Paper

Caliper	0.038 in.
Ream Weight	157 lb
Tear	
Length	24 g
Cross	28 g
Tensile	
Length	2 lb
Cross	2 lb
Moisture	3.5 %

Table VI shows the air resistance and smoke penetration characteristics of the paper as it was sampled directly from the paper machine over a period of one and one-half hours.

TABLE VI

Performance Data of Samples Taken Directly from Paper Machine

Sample	DOP Penetration (%)	Resistance (mm H_2O)	Efficiency (%)	Flexed DOP Penetration (%)	Flexed Resistance (mm H_2O)	Flexed Efficiency (%)
1	.025	111	3.24	.020	103	3.53
2	.034	108	3.21	.020	97	3.81
3	.042	113	2.98	- - -	- - -	- - -
4	.025	112	3.21	.021	99	3.72
5	.040	111	3.06	.025	99	3.64
6	.030	112	3.14	- - -	- - -	- - -
7	.024	116	3.12	.019	116	3.21
8	.019	121	3.08	- - -	- - -	- - -
9	.030	125	2.82	.028	110	3.23
10	.014	126	3.06	.022	112	3.26
11	.020	123	3.00	- - -	- - -	- - -
12	.017	123	3.06	- - -	- - -	- - -
13	.016	122	3.11	.022	115	3.18
14	.040	113	3.00			
15*	.095	85	3.55	Too weak for flexing.		
16†	.038	98	3.49	Too weak for flexing.		

* Spray-treated, no calender
† Spray-treated, calendered

These data show an initial performance quite superior to any type H-60 paper made at this mill. The last two samples were spray-treated on the machine with regular production equipment. In spite of the increased performance, the treated paper was so weak that it was difficult to handle on the rewinder. If the spray-treatment were to be used,

the furnish would have to be changed to give a stronger sheet or the weight and thickness increased to a maximum possible.

Samples 15 and 16 in Table VI were too weak to be flexed in the normal way, but it will be observed that the efficiency of these samples is at least as high as the average of the flexed samples that were not spray-treated. Although this information is limited to only two samples, there is a definite indication that the wetting agent minimizes the flexing effect.

On further study of this paper, two serious objectives were noted. The rate of DOP "break" was very high and the paper showed a relaxation effect on aging.

Effect of DOP Exposure

Table VII shows the effect of DOP exposure on performance.

TABLE VII

Effect of DOP Exposure on Performance of N-3 Sample

Time of Exposure (Min.)	DOP Penetration (%)	Resistance (mm H_2O)
0	.036	114 mm
1	.053	115
2	.065	116
3	.078	116
4	.083	$116\frac{1}{2}$
5	.087	117
6	.096	117
7	.100	117

This rate of "break" is faster than normal. However, it was later demonstrated that this was due at least in part to the bulking of the paper caused by the high flow of air through the sample while under test. This effect was greatly minimized by supporting the downstream side of the sample with a piece of 12x20 mesh gauze. In effect, this procedure should pack the fibers rather than bulk them. Table VIII gives the rate of "break" of a sample supported by gauze.

TABLE VIII

Effect of DOP Exposure on Performance of Gauze-Backed N-3 Trial Sample

Time of Exposure (Min.)	DOP Penetration (%)	Resistance (mm H_2O)
0	.024	121
1	.024	123
2	.026	125
3	.028	127
5	.033	128

This would seem to indicate that the rate of "break" of the N-3 paper was largely due to the deformation of the fibers in the sheet while under test rather than to any particular fiber or combination of fibers.

Relaxation with Aging

The relaxation effect was noticed when samples of the N-3 paper were retested after two to four weeks of normal atmospheric aging. Samples were selected which showed original penetration and resistance readings comparable to those in Table VI. In all cases tested, the paper showed higher penetration and somewhat lower resistance readings after aging. Table IX gives typical data showing this effect in the first four columns. The last three columns show the effect of recalendering these samples through a small steel-roll hand calender at medium pressures.

TABLE IX

Performance Data of Samples after Atmospheric Aging (2-4 Weeks)

Sample	DOP Penetration (%)	Resistance (mm H_2O)	Efficiency (%)	Recalendered DOP Penetration (%)	Recalendered Resistance (mm H_2O)	Recalendered Efficiency (%)
1	.090	110	2.77	.035	113	3.06
2	.100	110	2.73	.028	132	2.67
3	.080	109	2.84	.020	115	3.21
4	.090	108	2.82	.017	111	3.40
5	.068	112	2.83	.014	115	3.35
6	.075	111	2.82	.012	115	3.41
7	.068	113	2.81	.018	116	3.22

The above samples were all taken from untreated paper (without spray). However, the spray-treated paper showed the same effect to about the same degree. It will be observed that the recalendered samples show a performance approximately equal to those taken directly from the machine and recorded in Table VI. This would seem to indicate that the sheet bulks on standing. This effect has also been noticed to a lesser degree on some of the regular H-60 paper and was thought to be due to too heavy calendering. If this be true, the relaxation can be minimized by using less weight on the calender and decreasing penetration by adding more asbestos or simply by increasing the weight and thickness of the sheet.

Effect of Flexing

As can be seen from Table VI, the effect of flexing N-3 paper is very evident. Two or three sharp flexes across a desk top serves to reduce both the penetration and resistance readings. Spray-treating the paper on the machine definitely increases the efficiency to a point where it might be considered almost comparable to the best flexed samples. It is reasonable to assume that if spray-treated paper could be made strong enough for the purpose without sacrificing performance, the flexing effect would be greatly minimized and a superior filter paper would be realized. By reference to Table V and to samples 15 and 16 in Table VI, it can be seen that the weight and caliper of this paper could be increased by as much as 25-30% to give a sheet having a ream weight of approximately 200 pounds and a caliper of approximately 0.050". This paper would have a calculated resistance of 120 mm H_2O and a DOP smoke penetration of about .006%. It can also be

assumed that the strength would be increased by about 25-30%.

Flow Rate vs Penetration

Flow rate studies on the machine-made paper showed substantially the same performance as those on the laboratory handsheets recorded in Table IV. There is every reason to believe that there were no pin holes and that the asbestos distribution was good.

RECOMMENDATIONS

In view of the fact that the N-3 run yielded a filter material far superior to any other non-esparto paper, it is recommended that later trials be planned around this furnish to see what improvement can be made on the relaxation and the DOP "break" effect.

It is further recommended that more work be done on spray-treating this paper with a wetting agent to determine if the effect can be minimized.

RESEARCH AND MILL TRIAL AND THE DEVELOPMENT OF A DOMESTIC SUBSTITUTE FOR ESPARTO FIBER IN THE NAVY TYPE H-60 FILTER PAPER (N-4 TRIAL)

INTRODUCTION

This report covers the work done for the second quarter of Contract No. N60RI-209. A statement of the general objectives and an outline of previous work accomplished is contained in NRL Report C-3172.

The mill trial reported here is designated as the N-4 trial, H & V Lot No. 9913, dated March 17, 1947.

Based on the satisfactory results obtained with the N-3 furnish which contained neither esparto nor yucca fibers, it was decided to continue work on a similar furnish but to vary the proportions of the constituents and the methods of handling as indicated by laboratory work and experience.

LABORATORY WORK

In review, the N-3 furnish consisted of:

10% Rope
40% Causticized kraft
25% Cotton flock
10% Viscose rayon flock (1.5 denier)
15% Blue Bolivian asbestos

This furnish made excellent initial paper which improved with flexing. The effect of flexing was partially duplicated by spraying with a solution of a wetting agent. However, the sprayed paper was so weak that it was difficult to handle, particularly on the rewinder. The resistance of the spray-treated N-3 paper was low enough to increase the weight of the sheet 25-30%, hence a proportional increase in the strength could be realized. The rate of "break" of N-3 paper to DOP was faster than normal, but when the sheet was backed by gauze this effect was minimized, which indicated that the "break" was largely due to physical deformation or bulking of the sheet caused by the high rate of air flow during testing. Further, the N-3 paper relaxed on aging; it lost efficiency by increased penetration accompanied by a slight decrease in resistance. It was demonstrated that by recalendering the performance of the relaxed paper could be improved to approximately the original degree. This effect might be minimized by using less calender on the machine or might be compensated by decreasing penetration and overstepping resistance by addition of excess asbestos or by increasing the weight and thickness of the original sheet so that the final sheet would have the desired characteristics after relaxing. The distribution of asbestos in the sheet appeared to be satisfactory, as indicated by the Flow Rate

vs Penetration study; hence it was assumed that the combination of fibers used was adequate.

From studies made in the laboratory it was found that increases in the amount of causticized kraft in the furnish permitted addition of extra asbestos. The furnishes tested consisted of two types (on a weight basis, not including asbestos);

Type I (N-3 furnish)

10 Rope
40 Causticized kraft
25 Cotton flock
10 Rayon flock (1.5 denier)

Type II

10 Rope
50 Causticized kraft
10 Cotton flock
10 Rayon flock (1.5 denier)

To the two basic type furnishes, Blue Bolivian asbestos was added in increasing amounts as a percent of the final total weight, and the physical properties of resistance and caliper were checked. Typical handsheet data are recorded in Table I.

TABLE I

Effect of Asbestos on Resistance and Caliper of Handsheets

Furnish Type	Asbestos (%)	Resistance (mm H_2O)	Caliper (in.)
I	15	110	.039
I	20	116	.033
II	15	100	.050
II	20	78 (110)*	.027(.038)*
II	30	108	.034

* Calculated Values

It appears that a Type II furnish will accomodate more asbestos than a Type I furnish (N-3 paper). It was realized that these data could not be duplicated on the machine because of wet pressing (decreased caliper and increased resistance) inescapable in machine production that is not duplicated in handsheet production; however the fundamental trend of increased causticized kraft permitting increases in asbestos concentration should be applicable to both processes. The exact increase in the amount of asbestos permitted by increases in causticized kraft could be ascertained only on the machine.

Handsheets of the Type I and Type II furnish were checked for filtering efficiency, and typical data are recorded in Table II.

The samples made from the Type II furnish show an improvement over the samples from Type I (N-3 trial). As expected, increases in the amount of asbestos materially

TABLE II

Performance Data of Handsheets of Type I and Type II Furnish

Type	Asbestos (%)	DOP Penetration (%)	Resistance (mm H_2O)	Efficiency (%)	Flexed DOP Penetration (%)	Flexed Resistance (mm H_2O)	Flexed Efficiency (%)
I	15	.090	125	2.44	.062	113	2.84
I	15	.070	132	2.39	.045	114	2.94
II	20	0.850	82	2.53	.440	78	3.02
II	20	1.50	75	2.44	.800	72	3.06
II	20	.19	88	3.19	Sprayed with wetting agent.		
II	20	.17	94	2.95	Sprayed with wetting agent.		
II	30	.026	115	3.12	.022	107	3.42
II	30	.085	104	2.93	.046	104	3.25

increased the efficiency. The optimum amount of asbestos would be determined by the physical properties of machine-made paper, but as indicated by the previous data this amount would exceed that in the N-3 trial.

The effect of flexing is recorded above, and the treatment of the samples with a wetting agent seems to duplicate the effect of flexing. Several types of wetting agents were tested, but no appreciable difference was found between various wetting agents used in the laboratory in conjunction with paper treatment.

The rate of "break" on gauze-backed Type II paper was checked over a period of five minutes as recorded in Table III.

TABLE III

Effect of DOP Exposure on Performance for Gauze-Backed Type II Paper (20% Asbestos)

At Start: DOP Penetration (%)	At Start: Resistance (mm H_2O)	After Five Minutes Exposure: DOP Penetration (%)	After Five Minutes Exposure: Resistance (mm H_2O)
0.440	78	0.700	82
0.800	72	1.000	76

The rate of "break" indicated above is high, but approximates that of the N-3 paper. Though data is not available on this type of furnish, increased amounts of asbestos decreased the rate of "break" in other furnishes, hence a decrease in "break" could be expected if the amount of asbestos were increased. The reason for differences in the rate of "break" for various furnishes can not be definitely explained at present, but this factor is being studied carefully.

Further, by observation of DOP penetration at various flow rates the Type II paper showed a normal decrease in penetration with decreased flow rate which indicated that good distribution of asbestos was being realized.

All handsheet data were obtained at least one week after sheet formation to minimize any errors due to the relaxation effect.

THE MILL RUN

Preparation of Stock for Mill Trial

The preparation of the causticized kraft was carried out according to a standard procedure followed at this mill as outlined in the N-3 trial run.

Manufacturing Data for N-4 Trial

Each of two beaters was furnished with the following:

330 lb	Causticized kraft	- 55%
60 lb	Cotton flock	- 10%
60 lb	Viscose rayon flock (1.5 denier)	- 10%
60 lb	Rope fiber (prepared)	- 10%
90 lb	Blue Bolivian asbestos	- 15%
600 lb		100%

The asbestos was furnished to the beater first and given a hard beat for about 15 minutes. The asbestos was checked and found to be well defibered.

The beater roll was then raised and the asbestos was circulated as the remainder of the stock was added. The causticized kraft was added first followed by the rope, cotton flock, and rayon flock. The stock was circulated until thorough by mixed and it was then dropped to a chest from which it was pumped to a Fourdrinier machine for felting into paper. Approximately 3 to 5% additional asbestos was added from the auxiliary asbestos feed line.

In an effort to minimize relaxation upon aging caused by too much calender, the top roll of the calender stack was jacked up permitting the use of three light rolls as compared with the usual four heavy rolls.

The paper was sprayed with a wetting agent as indicated below. No great difficulty was experienced in formation or handling on the machine, but the sprayed sheet was weak and proved somewhat difficult to handle on the rewinder.

Performance of the Paper

Averages of physical tests on the 5% spray-treated paper are recorded in Table IV.

TABLE IV

Physical Tests of N 4 Paper

Caliper	0.0356 in.
Ream Weight	152 lb
Tear	
Length	27 g
Cross	31 g
Tensile	
Length	1.6 lb
Cross	- - -
Moisture	3.5%

In passing it should be noted that the tear and tensile tests are not considered too accurate because of their low range. However, this paper handled well and it is felt that there would be no difficulty in fabrication of the filter in the Navy canister.

Table V is a record of air resistance and smoke penetration characteristics of the paper as it was sampled directly from the machine over a period of about two hours.

TABLE V

Performance Data of Samples Taken Directly from Paper Machine

Conditions of Manfacture	DOP Penetration (%)	Resistance (mm H_2O)	Efficiency (%)	Flexed DOP Penetration (%)	Flexed Resistance (mm H_2O)	Flexed Efficiency (%)
5% Spray, 3 nips 3 to 5% Asbestos	.015	120	3.19	---	---	---
Added	.020	118	3.14	---	---	---
	.038	112	3.06	.044	105	3.20
	.020	117	3.16	---	---	---
2½% Spray, 3 nips 3 to 5% Asbestos	.030	117	3.01	---	---	---
Added	.038	116	2.95	---	---	---
	.020	120	3.08	.028	109	3.25
	.018	117	3.20	---	---	---
	.100	100	3.00	---	---	---
No spray, 3 nips 3 to 5% Asbestos						
Added	.068	118	2.69	---	---	---
	.068	115	2.75	---	---	---
	.060	114	2.86	---	---	---

The above data represent the initial performance of a paper that easily meets the existing Navy specifications for type H-60 Filter Paper. From the results obtained in the N-3 and the N-4 mill trials it seems reasonable to assumed that causticized kraft can be substituted successfully for either esparto or yucca without any loss in initial efficiency. The initial efficiencies realized in both runs seem superior to any results obtained thus far.

The improvement of the paper with spray-treating is definite as indicated above; however, further increases in efficiency may be realized by flexing the treated paper. The effect of varied concentrations of wetting agent, 2½% and 5%, is not too marked, though it is felt that the higher concentration probably gives a paper with better smoke filtering performance without materially decreasing physical strength.

The amount of asbestos in the N-4 furnish exceeds that in the N-3; however, the increase, 3 to 5%, did not influence filtering efficiency to any discernible degree. It is impossible, at present, to explain the fact that efficiency was not increased with an increase in the amount of asbestos. Evidentally there are factors influencing efficiency that have escaped detection but that should be identified and controlled.

With further study this paper showed the same disadvantages as the N-3 paper, i.e., high rate of "break" and a relaxing effect on aging.

Effect of DOP Exposure

Table VI shows the effect of DOP exposure on performance of a typical gauze-backed sample tested directly from the machine.

TABLE VI

Effect of DOP Exposure on Performance of Gauze-Backed N-4 Trial Sample

Time of Exposure (Min.)	DOP Penetration	Resistance (mm H_2O)
0	.035	123
1	.046	124
2	.052	126
3	.060	127
4	.064	128
5	.069	129
6	.078	130

This paper showed a faster than normal "break", but it was suspected that these "break" data included the relaxing effect. A similar sample was permitted to age for about three weeks before testing and no measurable "break" was noticed in a 5-minute test. It appears in recording "break" data on this paper that care should be taken to exclude any possible relaxing effect.

Relaxation with Aging

A relaxing effect upon aging (increased penetration accompanied by a small decrease in resistance) had been noticed on paper made in the past, and an object of this run was to study this behavior.

Table VII contains data on two separate samples tested at various time intervals.

TABLE VII
Effect of Aging on Performance of Two Samples

Interval after Manufacture (Approx.)	Sample I		Sample II	
	DOP Penetration (%)	Resistance (mm H_2O)	DOP Penetration (%)	Resistance (mm H_2O)
No Interval	.025	122	.010	119
3 Hours	.064	115	.14	114
6 Hours	.085	113	.18	115
10 Days	.078	109	.18	113
24 Days	.080	108	.14	112

It appears that these samples, exposed to atmospheric aging, relaxed very rapidly in the first 3 to 6 hours after manufacture and then assumed a more or less stable behavior.

Typical aging results on samples with and without spray are outlined in Table VIII.

TABLE VIII

Effect of Aging on Performance of Samples With and Without Spray Treatment

Interval After Manufacture (Approx.)	5% Spray		2½ Spray		No Spray	
	DOP Penetration (%)	Resistance (mm H_2O)	DOP Penetration (%)	Resistance (mm H_2O)	DOP Penetration (%)	Resistance (mm H_2O)
2 hours	- - -	- - -	.040	120	.25	112
4 hours	.071	120	.080	120	.18	103
10 days	.072	115	.080	116	.32	110
24 days	.062	116	.080	112	.25	109
Recalendered after 24 days	.025	136	.044	120	.09	121

The data on each sample are not consistant, however, the trends are discernible. As indicated previously in Table VII, the data in Table VIII show that this paper relaxed quickly in the first few hours and then assumed a rather constant behavior. Spray treatment seems very beneficial in minimizing the relaxing effect on this paper. More data should be obtained to determine the reproducibility of the above results.

The fact that the relaxed paper may be "revived" to approximately its initial performance by recalendering as shown in Table VIII indicates that the sheet is bulking on aging and that probably new passages are opened in the sheet as indicated by a lower resistance. Possibly, however, these new channels lack filtering ability as evidenced by the increase in penetration. Though a final solution to the problem is not apparent, two possible solutions offer themselves: producing a sheet in which no calendering takes place, or producing a sheet in which any calendering taking place is permanent.

Effect of Flexing

It can be seen from Table V that spraying the paper with a wetting agent will increase the efficiency but not to a point attainable by flexing. Though there is not too apparent a difference in effect due to wetting agent concentration, it is felt that a 5% concentration will increase efficiency more than a 2½% spray with little sacrifice in strength.

In an overall consideration, spray treatment is a possible, though not so good, substitute for flexing.

Flow Rate vs Penetration

It has become standard practice to check penetration at various flow rates to determine asbestos distribution. Paper having good asbestos distribution has a penetration that decreases with decreased flow rate. From a study of flow rate vs penetration it appears that the N-4 paper had no pin holes and that good asbestos distribution was realized.

RECOMMENDATIONS

In comparison with the N-3 paper, the N-4 machine-made paper contained more asbestos but illogically had a somewhat lower initial efficiency. In view of the opposite results obtained with experimental handsheets, it is recommended that more work be done on the evaluation and preparation of the stock and the asbestos.

It is apparent that relaxation with aging is a problem demanding continued investigation.

Further effort should be expended toward minimizing the flexing effect and the DOP "break".

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